

## Changes in humidity and temperature inside the pine cones (*Pinus sylvestris* L.) in two stages seed extraction

Monika Aniszewska

Warsaw University of Life Sciences – SGGW, Faculty of Production Engineering, Department of Agricultural and Forest Machinery, ul. Nowoursynowska 159, 02-776 Warszawa, Poland.

Tel. +48 22 5934511; e-mail: monika\_aniszewska@sggw.pl

**Abstract.** Temperature measurements were taken: (1) under opening scales, (2) at the seed, and (3) in the stem, of pine cones. Changes in temperature were only examined during the second stage of a two-stage seed extraction process. During this phase a permanent dehydration temperature of 50°C was used, following comparison over a ranges of temperatures, between a lower limit of 35°C and a higher limited of 50°C. The temperature was slowest to increase in the cone's stem, and fastest to increase under opening scales. The temperature at the seed remained constant at around 43°C for the first hour of dehydration, before increasing to 50°C. The two-stages method of cone extraction employed here, with a permanent dehydration temperature of 50°C in second stage, can be used in extraction cabinets equipped with seed extractors that allow the continuous control of air humidity. The time spent soaking during the inter-stage break should last 5 minutes. Viability of seeds obtained in two-stages process was 78% to 89%.

**Key words:** seed extraction, scale, pine cone, thermocouple

### 1. Introduction

Under natural conditions, the seeds of Scots pine (*Pinus sylvestris* L.) ripen in autumn in the second year after pollination; cones on trees open up in spring of the following year and seeds scatter during two or three weeks, depending on weather conditions. The most convenient term of economic cone collection is the late-autumn period, after the first frost. At that time, the seeds in cones are already ripen and scales, which become ligneous as a result of solar radiation, easily deviate and release the seeds. In Poland, cone extraction for forest management needs takes place in one of sixteen seed extractories, which have appropriate infrastructure for realization of the procedure. Generally, in seed extractories fully automated technologies are used, using known procedures for chosen species. However, for some pines species, using these devices can lead to ineffective cones extraction (e.g., requiring a long time for drying) and at the same time result in the opening of

a small number of scales, thereby leading to collection fewer seeds.

The precursor of polish pine seed extracting was described by Tyszkiewicz (1938), who was inspired by Hacks research (after Tyszkiewicz 1938) and showed dependency between temperature and air humidity inside the extraction chamber. He established the conditions for proper cone extraction and to obtain seeds without any loss of their vitality. The drying parameters recommended by Tyszkiewicz are still applicable and are used in Polish seed extractories. However, their disadvantage is their relatively long time of extraction (around 48 h).

Cone extraction for obtaining seeds is an energy-intensive process. One of the methods of limiting the energy expenditure can be the introduction of better process control methods, which will only be possible when we get to know the dynamics of the extracting process for which the signs are: changes of temperature and air humidity inside the chamber and changes of temperature of dry material and water content in it.

Attempts to reduce the time of cone extraction were undertaken by Antosiewicz (1978), by increasing the drying temperature while still maintaining its proper humidity. Increasing the temperature to 70°C, of spruce's cone extraction with a 12% humidity did not negatively influence the quality of the obtained seeds. The process of extraction in higher temperature (65°C), and the Monterey pine (*Pinus radiata*) was conducted by Farooqui and et al. (2000). Due to their research, seeds obtained from cones were also characterised as good quality. Nevertheless, currently in seed extractors, such high extraction temperatures are not used. High temperature can quicken seeds aging. In extraction cabinets currently used, the temperatures in the final phase of process do not exceed 50°C. Own observations indicate, that in some seed extractories it is even around 45°C, which in turn lowers the risk of seeds damage, but essentially extends the time of seeds extraction. It is not known however, how longer exposure for higher temperature affects the seeds vitality, especially those meant for long-term storage.

Used in seed extractors, one-stage (continuous) extraction process is not always appropriate for all Scots pine parts. Gradual increasing of temperature in extraction cabinet depending on air humidity is not sufficient stimulus for full cone opening and obtaining the seeds. Some cones, especially those obtained in initial collecting period, are 'resistant' and will not open. For those cones, multi-stage process may be used (two-, and three-stage), which will allow obtaining more seeds. This process relies on extraction interruption in its course, sprinkling or soaking cones in water and re-drying, like with acquisition of European larch, or pine *Pinus roxburghii* (Dinesh Kumar Srivastava et al. 2006). Such intervention causes a scale movement which is close to natural process of cones opening on the trees.

In national and foreign literature, there weren't any information found as regards the description of temperature changes in cones during the process of drying, and available studies which referred to measurements of this parameter inside of wood and agricultural products during convection drying (Kubiak, Laurow 1994; Jaros 1999). Learning the course of temperature change during cone extraction has a practical meaning. Typically, in multi-stage process, after sprinkling, and then again after putting cones into the extraction cabinet, it may not come to lowering of seeds vitality, for instance as a result of their infusion, mainly when seeds are still located in closed and humid

cone. This will not happen, when we will use a gradual increase of air temperature inside the chamber, but this action increases only the drying process.

In the thesis presented herewith, there are changes in cone temperature (between opening scales, at the seeds and in stem) after soaking, when temperature in extraction chamber was 50°C. The increase of drying temperature in second phase affects the speed of this process; however what is still needed to be known is what the temperature is in individual parts of cones, and especially at the seed. It will allow assessing the risks ensuing from the use of equally high temperature in the first phase of drying. Additionally it can be determined, after how long the individual elements of cones reach the temperature close to the temperature inside the dryer.

## 2. Materials and methods

For research, cones were used from Barycz Forest Inspectorate (Regional Directorate of State Forests – Radom), brought in 2011 form economic extractory in Grotniki. Fresh cones were kept in laboratory in refrigerator.

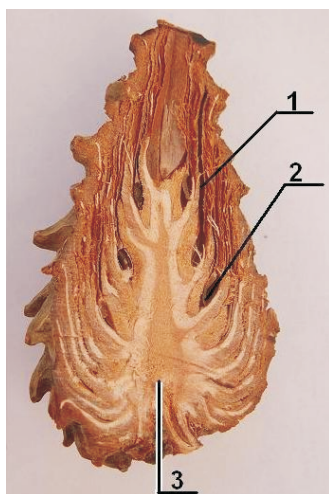
Randomly chosen cones underwent an extraction process in Heraus UT 6120. During the research, conducted in a room and in dryer, the temperature and the relative air humidity were registered with the use of hydrometer Hydro-Palm 3.

Directly before extraction, cones were marked, and then with the use of slide caliper its length and thickness were measured with accuracy up to 0,1 mm, and weighed with accuracy up to 0,01 g. A classification of cones according to Pravdin (1964) was made for cones of chunky shape ( $2,0 < h/d < 2,5$ ), ovoid shape ( $1,5 < h/d < 2,0$ ) and long shape ( $2,5 < h/d < 3,0$ ).

The cones were divided in 5 parts with 35 cones in each part and placed successively in the laboratory dryer.

Four parts were dried with two-stage process, and one for comparison with one-stage process. In the first phase of two-stage process cones were dried for 5 and 7 hours. Every hour, a measurement of mass of every cone was made and seeds were shaken out. After completing the first phase of extraction, cones were soaked in water with a temperature of 30°C ( $\pm 2$ ) for 5 and 15 minutes. The cones were taken out of the water, drained from excess water and left for 1-hour break. Subsequently in selected cones, thermo-couples type K (MiCh-NiAl) was placed, and then cones were again put into a dryer, to

be dried further. Thermo-couples were attached: under opening scale, at the seed in the middle part of cone, and in the cone stem at its base (Fig. 1). Thermo-couples in stems of individual cones were placed in holes with the use of drill with the drill bits of diameter 1,0mm. The temperature was automatically registered every minute with the use of multiple temperature recorder WRT-9.



**Figure 1** View on cut cone with placed within thermo-couples: 1 – under opening scales, 2 – at the seed in the middle part of cone, and 3 – in cone's stem

In the second phase of cone extractions, cones were kept in the dryer for 6 hours, and the temperature measurements inside the cones were made for about 4 hours (240 min). At this time majority of scales were bend aside.

During drying, the temperature inside the dryer was 25°C in the first phase – for the first two hours, and then – for another three or five hours (depending on the variant) – 50°C. In the second phase, temperatures of drying were programmed at 50°C (Aniszewska, Petrenko 2012). In order to compare the results, a study was performed, in which a temperature of drying air in second phase was initially established at 35°C, and after two hours was increased to 50°C. This time, the measurements of temperatures inside of cone were made for about 5 hours (290 min).

Finally the research of temperature measurements inside the cones were made in the following variants of two-stage process, with constant and variable temperature (for the ones selected) in second phase: 5.5.1.6, 5.15.1.6, 7.5.1.6, 7.15.1.6, wherein the first number stands for the time of first phase in hours, second – time of soaking in minutes, third – time of break

before second phase in hours, fourth – time of second phase in hours. The time of temperature measurements were shorter from the drying time in the second phase.

The seeds collected from cones were manually de-winged and cleaned, and then put on Jakobsen apparatus, for each variant four times with 100 seeds each. To evaluate their vitality, the energy of germination after 7 days, and germination capacity after 21 days were defined (Załęski, Aniśko 2003).

After cone extraction, they were dried in a temperature of 105°C ( $\pm 2$ ) to the state of dry weight, in order to calculate the humidity in individual phases of process.

Two statistical analysis chosen were the most often used measurements: the arithmetic mean and standard deviation and *T* test, Kruskal-Wallis and *F* test. The calculations and statistical tests were made with the use of program Statistica (StatSoft Inc. 2009).

### 3. Results

#### 3.1 Characteristics of selected features of cones

Examined cones had length from 31,5 to 53,33 mm, thickness from 14,8 to 22,8 mm and initial mass from 3,44 to 10,82 g (Table 1) what was consistent with the values given by Staszkievicz (1993) for Scots pine.

Cones extracted in two-stage process from part 5.5.1.6, 5.15.1.6, 7.5.1.6 did not differ significantly, and therefore it could have been treated as only one part. Calculated double average (average of the average) for those 3 parts were: for length – 41,35 mm, thickness – 18,90 mm and mass – 5,83 g. Cones from part 7.15.1.6, and cones extracted with one-stage process were shorter for about 2 mm and thinner for about 1 mm. Cones extracted in one-stage process like part 7.15.1.6, were homogeneous in the terms of length, thickness, mass and differed substantially from the three remaining.

Due to Pravdin classification (1964), under examined collection, most of the cones were chunky shaped – 86,5%, next ovoid shaped 11,2% and the least numerous were long cones – 2,3%. Own size observations of cones from Poland indicates that most cones are chunky shaped.

Among cones from Barycz Forest Inspectorate, 'the plano' form prevailed, characterised by outgrowth of smaller than half of scute width. Moreover, under examined collection cones of form 'plana-gibba' (about 7,6%) were also distinguished, but there was no remaining forms mentioned in literature (gibba and refleksa).

**Table 1.** Basic parameters of extracted cones

Process	Variant*	Characteristics	Length	Thickness	Mass		
					at the beginning of 1st stage	at the beginning of 2nd stage	dry
			mm		g		
Two-stage	5.5.1.6	average	41,41	19,2	5,94	6,77	4,62
		standard deviation	3,25	1,35	1,25	1,30	0,91
		min	36,4	16,0	4,13	4,95	3,13
		max	49,3	22,8	10,82	11,52	7,97
	5.15.1.6	average	41,6	19,00	5,92	6,92	4,66
		standard deviation	3,17	1,60	1,00	1,04	0,75
		min	33,5	15,7	3,80	4,67	3,11
		max	48,7	22,4	8,82	8,61	6,47
	7.5.1.6	average	41,05	18,64	5,64	6,07	4,35
		standard deviation	2,79	1,29	0,99	0,947	0,71
		min	33,4	15,5	3,44	3,62	2,66
		max	45,6	21,5	8,15	8,06	5,86
	7.15.1.6.	average	39,2	18,00	5,07	5,92	4,02
		standard deviation	3,89	1,57	1,09	1,27	0,85
		min	33,5	15,5	3,81	4,01	2,99
		max	48,9	21,0	8,17	9,15	6,47
One-stage	-	average	39,28	17,85	5,10	-	3,98
		standard deviation	3,83	1,41	1,21	-	0,95
		min	31,5	14,8	3,56	-	2,80
		max	53,3	21,4	9,93	-	7,66

\* first number defines time of first phase lasting in hours, second – time of soaking in minutes, third – time of break before second phase, fourth – time of second phase lasting in hours

### 3.2. Conditions of process course

Temperatures registered on dry thermometer inside the laboratory dryer for the first two hours of first phase gradually increased from surrounding temperature of 22,5°C to a maximum of 35°C and averaged at about 33,6°C; and for another few hours – three or five, depending on the variant – averaged at about 49,6°C. The air humidity decreased from 54,2 to 13,5% with a temperature about 35°C and reached an average value 11,9% with a temperature of 50°C. In the second phase, with an average temperature of 50°C, the air humidity was approximately around 9,5%.

### 3.3. Change of cones mass and humidity

Knowledge of the cones' mass made it possible to determine the humidity of cones extracted with one-

and two-stage process, in characteristic moments of this process, which is on the beginning –  $W_{o1}$  ( $W_{o2}$ ) and in the end  $W_{k1}$  ( $W_{k2}$ ) of first and second phase (Table 2).

The average initial humidity of cones in the first phase for all five parts was from 26 to 29,7%, wherein the lowest was in case of part 7.15.1.6, and the highest in case of part 7.5.1.6.

The initial humidity of cones in second phase  $W_{o2}$  depended on the soaking time and it was lower in case of cones kept in water. In case of cones soaking for 5 minutes, its humidity increased by an average about 18,5% and in case of cones dried in first phase for 5 hours, and 10% in case of cones dried for 7 hours. When cones were soaked for 15 minutes, its humidity increased by the same amount – an average of 21,5%, regardless of drying time in first phase.

**Table 2.** Average humidity of cones in one- and two-stage process of extraction

Process	Variant*	Characteristics	Humidity of cones, %			
			in first stage		in second stage	
			initial $W_{o1}$	final $W_{k1}$	initial $W_{o2}$	final $W_{k2}$
Two-stage	5.5.1.6	average	28,2	14,8	46,7	10,4
		standard deviation	5,1	4,3	8,8	4,0
		min	20,9	8,3	22,4	3,4
		max	40,4	26,2	65,5	20,3
	5.15.1.6	average	27,0	14,4	48,9	11,9
		standard deviation	3,6	3,8	7,2	3,4
		min	20,4	8,9	29,9	6,0
		max	36,3	24,9	60,9	18,8
	7.5.1.6	average	29,7	12,0	39,9	7,6
		standard deviation	4,9	3,7	6,9	1,6
		min	22,6	7,8	20,6	6,0
		max	43,7	24,6	51,7	13,6
	7.15.1.6.	average	26,1	11,1	47,2	7,8
		standard deviation	2,8	2,9	8,1	1,6
		min	22,5	7,6	23,4	6,1
		max	33,7	20,1	64,6	12,6
One-stage	-	average	28,2	8,1	-	-
		standard deviation	2,4	1,1	-	-
		min	23,6	5,7	-	-
		max	32,7	10,8	-	-

\*variants – as in Table 1

The final humidity of cones after first phase of extraction ( $W_{k1}$ ) depended on time and averaged 14,6% for parts dried for 5 hours and 11,5% – for parts dried for 7 hours. While the final humidity after second phase ( $W_{k2}$ ) was 11,1 and 7,7% estimated respectively. Therefore with the same time of lasting of the second phase, the humidity of cones decreased by 3,5 and 3,8%.

In the first phase, the humidity of cones extracted for 5 and 7 hours decreased by 13% and 16% respectively, and in second phase, after soaking 5 min – by 36% and 32%, and after soaking 15 min – by 37 and 39% respectively.

In the total time of the drying process (11 and 13 hours) and soaking, on an average the cones lowered its humidity by 17,8% (variant 5.5.1.6) and 15,1% (variant 5.15.1.6) and by 22,1% (variant 7.5.1.6) and 18,3% (variant 7.15.1.6).

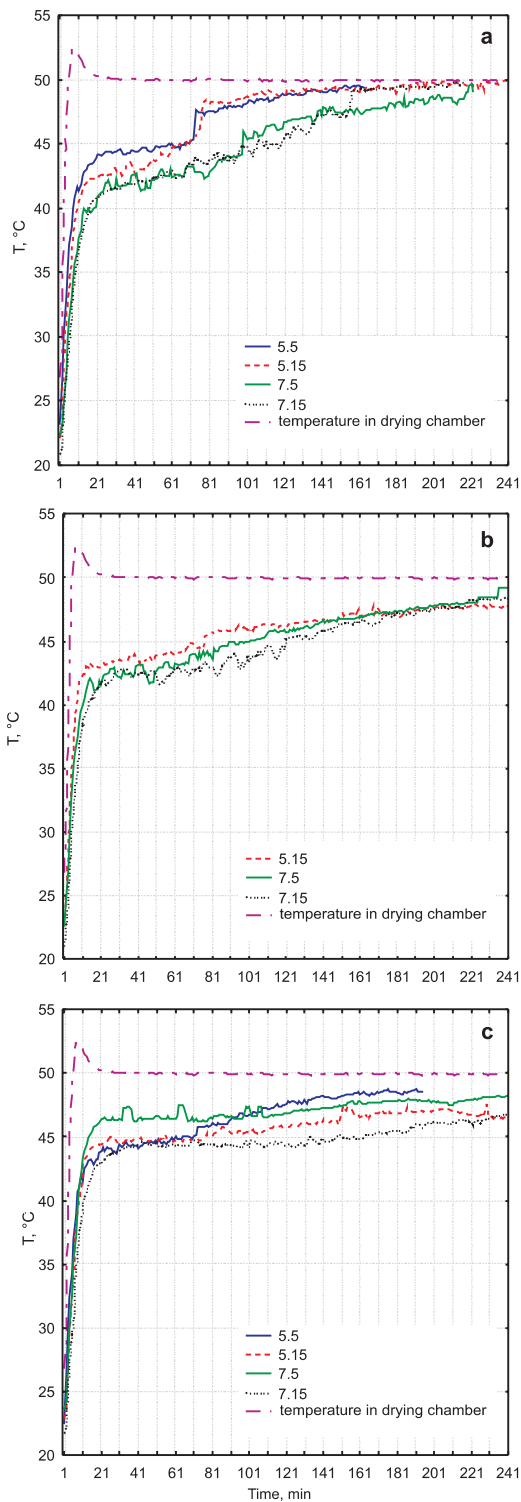
In one-stage process, after 13 hours of drying, the humidity decreased on an average from 28,2 to 8,1% which is by 20,1%.

For cones, weight loss also affected obtaining of seeds. In one-stage process, the seeds were released from cones gradually and after 13 hours 94% were obtained. In two-stage process after 5 hours, about 37% of seeds, and after 7 hours 58% of seeds were obtained. After the completion of the two-stage process, on an average 97,5% of seeds were obtained, wherein most were obtained in the variant of 7.5.1.6. – 98,4%.

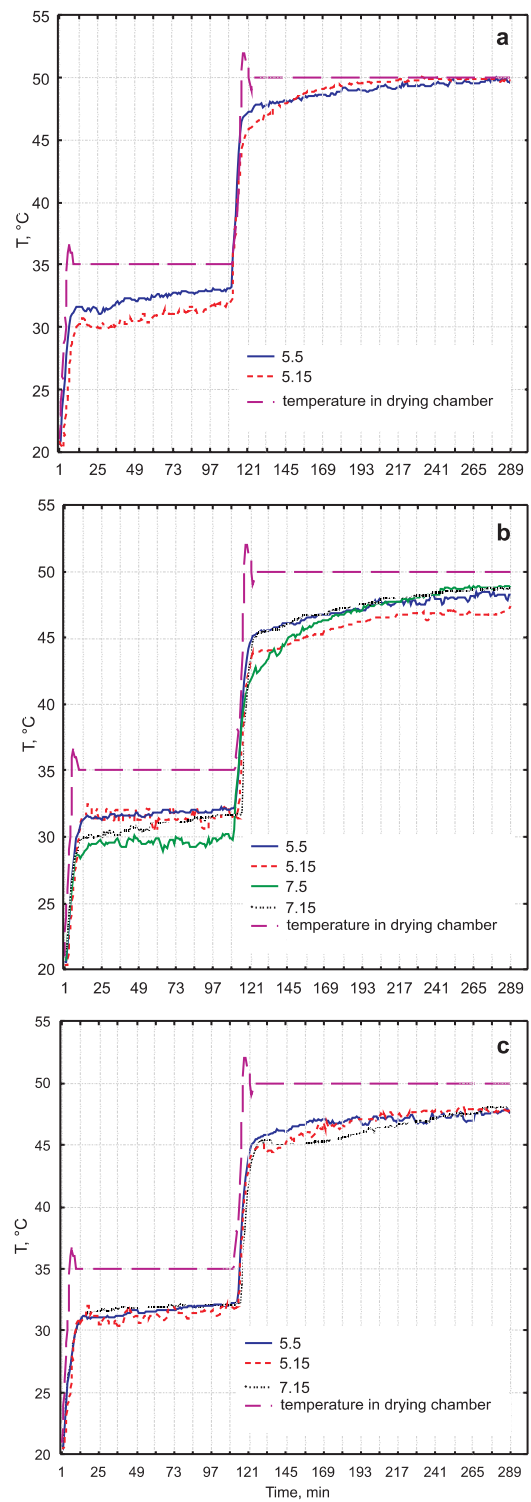
### 3.4. Change of temperature in extracted material

During the study, a temperature increase was observed in cones from 21°C to about 50°C. Figure 2a shows changes of temperature measured by thermocouples placed under an opening scale, on Figure 2b – changes of temperature measured at the seed, and in Figure 2c – in cones stem from the bottom (cone's base).

On each graph, a curve was shown illustrating a temperature change of dry thermometer registered in dryer during the process. It may be noticed that the



**Figure 2.** Course of temperature change in second phase of two-stage process of cone extraction : under opening scale (a), at the seed (b), and in cones stem (c)



**Figure 3.** Change of temperature during second stage of extraction: under opening scale (a) at the seed (b), and in stem (c)

temperature inside the dryer stabilised at a level of 50°C after about 7 minutes from switching it on and maintained at this level until the end of the extraction process.

Within the first minutes of the process, the temperature in cones quickly increased to about 45°C. Then for about 80 minutes, it stabilised, and then it increased to temperatures close to inside of the dryer. The temperature under opening scale (Fig. 2a) most quickly reached the level of the surrounding (50°C). It was caused by a scale deviation from stem and the reach of heated air to cone's interior. On the graph, there's a characteristic vertical line noticed picturing the temperature jump at the moment of scale movement. In case of cones extracted for 5 hours in the first phase, the temperature jump occurred in 70 minute, and in case of cones extracted for 7 hours – in 95 and 155 minute of second phase lasting.

The most slowly increased the temperature in cones stem (Fig 2c). After four hours of process there was no equalization of cones temperature with surrounding temperature. Additional study showed that not before about 7 – 8 hours of drying, the temperature inside the stem leveled with surrounding temperature.

By analyzing the changes of temperature for various drying times in the first phase and soaking before the second phase, it was stated, that in stem of cones soaking for 15 minutes, the temperature was lower than in those soaked for 5 minutes (Table 2c). Whereas the temperature at the seed (Fig. 2b) did not increase so suddenly, as under the opening scale. In each of the variants for the first hour of drying, the temperature was at about 42°C, and after that gradually increased to 48°C.

Temperature increase analysis was performed with changing temperature-humidity conditions, which in turn showed that with both the first and the second phase of drying, the temperature inside of the material did not

reach the inside temperature of the dryer. The exception was a part of cones, in which the thermo-couples were placed under opening scale (Fig. 3)

For the first two hours of process, when the air temperature was about 35°C, the temperature measured under scale was lower by 2–5°C, at the seed by 3–7°C, and in stem by 4–5°C. The temperature course measured in the stem did not differ significantly in individual variants.

In the second phase, when the temperature inside of the dryer reached 50°C, the temperature measured by thermo-couples was also lower. However, in the following hours of drying, noticeable was its gradual increase. On an average, during the four hours of drying, the temperature under opening scale increased by 3°C, at the seed by 4°C, and in stem by about 2°C.

The comparison of cones' temperature change course with various soaking time indicates, that temperature at the seed was lower after longer time of soaking cones (15 min). Temperature in this location differed depending on the time of first phase lasting time. Such cones on the beginning of second phase had also a higher humidity.

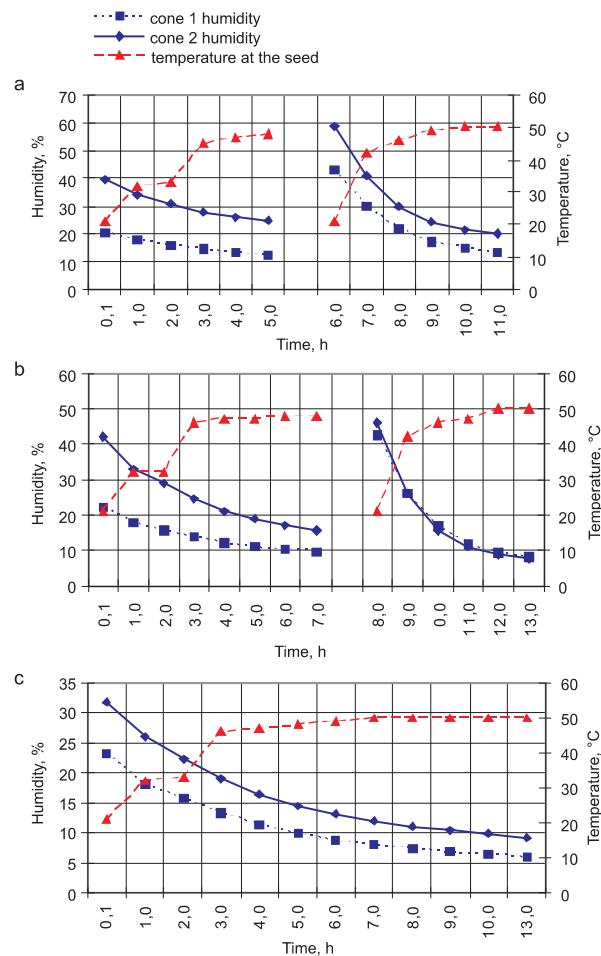
From parts selected, there were 6 cones differing in the initial humidity; Table 3 shows their basic parameters. The changes in the course of drying process are detailed on Figure 4.

Cones with higher initial humidity dried out more intensively, what could have been observed both in first and in second phase of extraction. Whereas the temperature of those cones measured at the seed did not differ significantly from the temperature of cones with lower humidity. After two hours of drying cones in 35°C, its humidity decreased from 39 to 30% and from 21 to 16% respectively. At this time, the temperature at the seed was about 32°C. In third hour of extraction, when the temperature of drying air was raised to 50°C,

**Table 3.** Basic parameters of examined cones

Process	Variant*	No.	Length	thickness	First stage		Second stage		Dry mass
					initial mass	humidity	initial mass	humidity	
			mm		g	%	g	%	g
Two-stage	5.5.1.6	1	38,5	19,2	5,96	21	7,15	43	4,93
		2	41,2	20,0	6,36	39	7,32	59	4,53
	7.5.1.6	1	41,8	18,2	5,48	23	6,48	45	4,47
		2	42,4	19,6	5,64	43	5,89	49	3,94
One-stage		1	39,8	18,0	5,12	24	-	-	4,14
		2	37,4	17,2	4,66	32	-	-	3,52

\*variants – as in Table 1



**Figure 4.** Changes of temperature measured at the seed in cones of various initial humidity in two-stage extraction with the first phase lasting 5 hours (a) or 7 hours (b) and 1-stage extraction (c)

the temperature at the seed reached the value of 46°C, and in fifth hour – 48°C. The humidity of cone in the third hour of process was 28 and 14% and in the fifth, 23 and 12% respectively.

After soaking the cones for 5 minutes, water content was raised therein. In the second phase of cones' extraction dried for 5 hours in first phase, when after an hour the air temperature was not lowered, the humidity of the two examined cones from lowered from the initial 59% to 43%, then to 40% and the 30%. At this time, the temperature measured at the seed increased from 21 to 41°C. After two hours of the most intensive change, an increase of temperature occurred to 46°C and lowering of humidity of both cones by about 10%.

At the end of process, the temperature at the seed equaled with the temperature in the dryer, and the cones' humidity was 20 and 12% respectively. Cone 2 (Fig. 4a) did not open completely, and its final humidity was higher.

Final cone humidity after the first stage of drying was extended to 7 hours, and then decreased finally to 17 and 10% (Fig. 4b). In the second stage, after 5-minute soaking time, the cones' humidity increased to about 49 and then 45% respectively. After an hour of drying, the cones reached a humidity of about 26% with the temperature at the seed at 41°C. At the end of drying, the humidity of cones decreased to 9%, and the temperature at the seed reached 50°C.

In one-stage cones drying process, in the seventh hour of the process, occurred equalization of temperature measured at the seed, in the middle part of cone, with the temperature of inside of the dryer (Fig. 4c).

### 3.5. Evaluation of obtained seeds

Based on energy and capacity of seed's germination in two-stage extraction under three variants – 5.5.1.6,

**Table 4.** Average number of germination seeds in different variants of experiment

Process	Variant*	Germination energy, %	Germination capacity, %		Vitality class
			after 14 days	after 21 days	
Two-stage	5.5.1.6	73	88	89	II
	5.15.1.6	69	77	78	III
	7.5.1.6	75	86	86	II
	7.15.1.6	76	81	82	II
One-stage	-	76	82	82	II

\*variants – as in Table 1

7.5.1.6, 7.15.1.6 and one-stage process, they were ranked to second vitality class, whereas the seeds obtained from cones extracted for 5 hours in the first stage and soaked for 15 minutes (variant 5.15.1.6) were ranked to third vitality class.

#### 4. Discussion

The study of two-stage process run in four variants (5.5.1.6, 5.15.1.6, 7.5.1.6, and 7.15.1.6) in comparison with one-stage process, which showed significant differences in change of mass loss and humidity in time, resulting from the use of humidification before the second stage. Humidification, consisting of five- or fifteen- minute soaking time and one-hour break, caused a significant increase of mass and cones' humidity in the beginning of the second phase. It resulted in a partial or complete closure of scales on cones, opened after the first phase of drying. On those scales, usually there were no seeds left.

In the second phase, the first opened scales, which were closed in the first stage, and therefrom the following seeds were obtained. It was noticed that in the second phase, opening of scales occurred faster than in the first phase. At the same time of effective extracting (without soaking time and break) in two-stage process, release of larger number of seeds occurred than in one-stage process.

Analysis of cones' humidity changes in time in four variants of two-stage process enabled stating that in case of examined cones, the best variant was 7.5.1.6. Even though initially the cones from this part had on average had the highest humidity at 29,7% at the beginning, and at the end of the second phase, they reached the lowest humidity 39,9 and 7,6% respectively. The loss of humidity in this phase was on an average at 32,3%.

In the first phase after 5 hours of extraction under a given criteria, the humidity of cones lowered on an average by around 13%, while after 7 hours by around 15%. Cones of higher final humidity in the first stage treated with soaking for 5 minutes, soaked with water more than cones of lower humidity. After soaking for 15 minutes, both cones of lower and higher humidity in the end of first phase caused equalization of their humidity.

Another six hours of extraction in the second phase, with constant temperature of 50°C, the air in the chamber caused reduction of their humidity by the water amount, which was absorbed by cones during soaking time and for shorter soaking time (5 min), for another 4,4%, and for longer (15 min)- i.e. on an average of 3%, towards the average humidity in the end of first phase.

With air humidity in the room at around 55%, the air in dryer had humidity over 10%, when its temperature reached 50°C. Such conditions allowed for obtaining Scots pine seeds of humidity around 4,3%, wherein the critical level of seeds humidity for this species, below which they should not be over-dried and therefore was established at 3,5% (Załęski et al. 2009).

Evaluation conducted shows, that seeds obtained in two-stage process reached germination capacity from 78 to 89%, which allows to include them to third class of vitality (variant 5.15.1.6) or second (seed from remaining three variants). Seeds obtained in one-stage process were included to second vitality class (82%). The reason for worse seed germination capacity obtained in two-stage process (third class of vitality, beside variant 5.15.1.6) may not be two-stage extraction process and used soaking, but inappropriate cones storage before extraction or extracted seeds or weather factors which may influenced unfavorably on seed development in cones (during its setting or ripening), or also climate or habitat conditions, in which the trees grew, which was confirmed by the research performed by Aniśko et al. (2006).

Registered changes of cones temperature in the time of extraction in distinguished research variants of one- and two-stage process allowed to state, that during drying of cones which were soaked, for safety should be used, firstly lower drying temperature, and then in second stage, higher, because a danger of seed damage may occur. This concerns mainly the cones, which strongly absorb water. The use in second phase, a constant drying temperature on level of 50°C is possible but requires maintaining low, around 10%, humidity inside the drying chamber. In modern extraction cabinets, the level of humidity doesn't drop below 20% (Aniszewska, Jaworski 2009). It is caused by large number of humid cones, from which drying water evaporates, causing the increase of air humidity inside the dryer. Reaching the humidity of 10% can be done by intensive air exchange in the cabinet, and with present technological development this isn't a problem. Proposed constant temperature of drying (50°C) in second phase causes increase of cones drying intensity and in case of some variants, shortens the time of effective drying in comparison to one-stage process.

Studies conducted indicate that the slower the increase of the temperature in the cones' stem, the quicker the rise in temperature under the opening scale. During the cones scale opening, under which a thermo-couple was placed, there's clearly a visible temperature increase. The temperature increase at the seeds is slower than under the opening scale. Initially, for the first hour, the temperature remains at a constant level, later it grows to 50°C.

Measurement of temperature inside cones during drying allowed only for presentation of temperature change inside the cones' stem. Whereas the measurement of temperature at the seed and under opening scale requires supplementing for humidity measurement. Presumably the humidity at the seed is different than the one registered in dryer during the process. Only these parameters will allow drawing conclusions, whether after soaking the cones may be extracted in constant temperature of 50°C.

## 5. Conclusion

1. Research conducted showed relevant difference in course of one- and two-stage process of Scots pine extraction, on what the significant influence of soaking of cones before the second phase in a two-stage process, causing an increase of their humidity.

2. Comparison of four variants of extraction process with constant temperature of 50°C during the second phase showed, that the most effective for examined cones is variant 7.5.1.6, and the least effective – 5.15.1.6. Due to a short span of time, the first stage of lasting (5 hours) caused the cones scales to not undergo enough deviation, thereby less seeds were extracted. Long time of soaking the cones (15 minutes), unopened in first stage of drying, which in turn caused a relevant mass increase, and thereby also a humidity increase. Cones soaked with water needed more time to evaporate water out of them, than those soaked in shorter time, in order to obtain from them more seeds in second phase. Therefore, soaking time should be around 5 minutes.

3. Constant temperature of drying (50°C) during second phase, especially after longer cones soaking, may be a reason for lowering seed quality, as evidenced by intensive temperature increase at the seed during drying and lower energy and seeds germination capacity. It concerns mainly the cones of higher humidity in the beginning of second phase.

4. The use of two-stage extraction process, with constant temperature in second phase, is possible under condition of maintaining low humidity in extraction chamber (around 10%) through intensive air exchange.

## Acknowledgements

The research was funded from financial resources of Faculty of Production Engineering, Warsaw University of Life Sciences – SGGW.

## References

- Aniszewska M., Jaworski S. 2009. Analiza dwuetapowego łuszczenia ze zraszaniem wodą szyszek sosny zwyczajnej *Pinus sylvestris* L. [Analysis of two-stage extraction of *Pinus sylvestris* L. seeds]. *Leśne Prace Badawcze*, 70 (4): 329–338.
- Aniszewska M., Petrenko Y. 2012. Evaluation of quantity and quality of common pine seeds (*Pinus sylvestris* L.) obtained in two-stage seed extraction process under laboratory conditions. *Annals of Warsaw University of Life Sciences – SGGW Agriculture*, 60: 129–136.
- Aniśko E., Witowska O., Załęski A. 2006. Wpływ warunków suszenia nasion brzozy brodawkowatej, olszy czarnej, sosny zwyczajnej i świerka pospolitego na ich żywotność [Effect of drying conditions on viability of common birch, black alder, Scots pine and Norway spruce seeds]. *Leśne Prace Badawcze*, 67 (2): 91–113.
- Antosiewicz Z. 1978. Doskonalenie procesów technicznych wyluszczenia nasion sosny i świerka [Improvement of technological processes of pine and spruce seed extraction]. Sprawozdanie nauk., Instytut Badawczy Leśnictwa, Warszawa: 1–24.
- Dinesh Kumar Srivastava, S. K. Negi, S. S. Pradeep Kumar. 2006. Development of technique for rapid extraction of seeds from cones of *Pinus roxburghii* Sarg. under controlled conditions. *Indian Forester*, 132 (2): 197–204.
- Farooqui, U. M. Dixit, R. K. Patra, A. K. Rayal, S. P. Khan, A. Tiwari, S. K. 2000. Effectiveness of different seed extraction methods on seed value from the cones of *Pinus radiata*. *Indian Forester*, 126 (9): 936–942.
- Jaros M. 1999. Kinetyka suszenia warzyw. *Rozprawy Naukowe Akademii Rolniczej w Lublinie*, 224: 1–71. ISSN 0860-4355.
- Kubiak M., Laurow Z., 1994. Surowiec drzewny [Wood raw material]. Warszawa, Fundacja Rozwój SGGW, p. 493. ISBN 83-86241-33-0.
- Pravdin L. F. 1964. Sosna obyknovennaja Izmencivost', vnutrividovaja sistematika i selekcija [Scots pine intraspecific systematic and selection]. Moskva, Izdatel'stvo 'Nauka'.
- Staszkievicz J. 1993. Zmienność morfologiczna szpilek, szyszek i nasion [Morphological diversity of needles, cones and seeds]. In: *Biologia sosny zwyczajnej* [Biology of Scotch pine] (eds. S. Białobok, A. Boratyński, W. Bugała). Poznań, Sorus, ISBN 83-85599-21-5.
- StatSoft Inc. 2009. STATISTICA (data analysis software system), version 9.0. www.statsoft.com.
- Tyszkiewicz S. 1938. Wyluszczenie nasion sosny [Pine seed extraction]. *Rozprawy i sprawozdania*, nr 35. Warszawa, Instytut Badawczy Lasów Państwowych: 1–95.
- Załęski A., Aniśko E. 2003. Suszenie nasion wybranych gatunków drzew. *Notatnik Naukowy Instytutu Badawczego Leśnictwa*, 1 (55): 1–4.
- Załęski A., Aniśko E., Kantorowicz W. 2009. Zawartość wody w podsuszanych nasionach drzew leśnych a wilgotność względna suszącego powietrza [Moisture content in dried forest tree seeds versus relative humidity of drying air]. *Leśne Prace Badawcze*, 70 (2): 151–160.

Translated by: Anna Wyszzyńska